Annual Report

to

The National Aeronautics and Space Administration

on

The Research Progress of

Grant NsG 708

on

Basic Research in Semiconductor Detector Dosimeter Characteristics, As Applied to the Problems of Whole Body Dosimetry

from

George W. Crawford
Professor of Physics
Southern Methodist University
Dallas, Texas, 75222

May, 1967.

Annual Progress Report

NsG 708

I. Experimental Progress

A. Lithium Drifted Silicon Semiconductor Detectors:

1. Seventy different detectors have been incorporated into this study. They represent a family of various sized devices ranging in size from 1 × 1 × 1 mm to 7 × 7 × 150 mm. Long detectors, i.e., having proton path lengths in silicon of 10, 20, 30, 50, 70, 100, 120, 130 and 150 mm are being used to totally absorb high energy protons. Shorter path lengths are used to measure stopping power $dE/\rho dX$ in silicon.
2. Lithium-drifted detectors of special shapes and sizes are fabricated at SMU. New techniques of fabrication, mounting and encapsulation were developed.
3. Combinations of detectors have been developed to permit simultaneous measurements of dE/dx and E with identification of both mass and energy of the incident particle for translation to a surface dose and depth dose distribution.

B. Charge-pulse response of silicon detectors:

The charge-pulse response of many of the detectors have been measured for the proton energies listed in D. as a function of proton energy, proton path length in silicon and operating conditions of the detector. The average energy required to produce an ion-electron pair has been measured from both the stopping power measurements in silicon and from the protons totally absorbed in silicon. These data are required to translate the current from each detector produced by a known radiation flux density and stored in a calibrated condenser into dose, i.e., the total energy absorbed per unit mass of silicon.

C. Detector Life-time Behavior Studies:

The depletion depth, volume, noise level, charge pulse per Mev, dark current and capacitance are being measured for each detector used in the study. The complete age-usage history thus obtained over the two year period will be used to (a) predict the usable life of a detector and (b) to pin-point and predict loss of reliability of data produced by the detector.

D. Stopping Power Measurements:

Data has been taken using protons having energies of 5, 6, 8, 10, 11, 12, 13, 14, 15, 16, 36, 37, 40, 100, 160, and 187 Mev. Absorbers were used in duplicate sets of three different thicknesses permitting measurements on six different absorbers with each of two or more detectors.

a. Elements: Al, Be, C, Cu, Fe, Pb, Si
b. Plastics: Nylon, plexiglass, polyethlene, tissue equivalent.
c. Tissue: Bone, muscle, fat.

E. Field Trips:

1. to the University of Texas, Austin, Texas
   Dates: October 10-11, 1964
   Accelerator time: 36 hours
   Proton Energies 5-14 Mev

   Dates: December 28-29, 1964
   Accelerator time: 36 hours
   Proton Energies 8-16 Mev

2. Oak Ridge National Laboratories, Oak Ridge, Tennessee
   Dates: November 21-29, 1964
   Accelerator time: 80 hours
   Proton Energies: 36-40 Mev

3. University of Uppsala, Uppsala, Sweden
   Dates: October 23-November 8, 1964
   Accelerator time: 100 hours
   Proton Energy: 187 Mev

4. University of Southern California, Los Angeles, California
   Dates: May 20-22, 1965
   Accelerator time: 24 hours
   Proton Energies: 21-30 Mev

5. McGill University, Montreal, Canada
   Dates: August 4-15, 1965
   Accelerator time: 110 hours
   Proton Energy: 100 Mev

6. Harvard University, Cambridge, Mass.
   Dates: August 16-19, 1965 NOTE: Cyolotron main generator failed just before SMU turn to "go on the beam." This major breakdown forced rescheduling field trip to
   Dates: January 18-24, 1966
   Accelerator time: 84 hours
   Proton Energy: 160 Mev

7. University of Uppsala, Uppsala, Sweden
   Dates: April 20-May 4, 1966
   Accelerator time: 138 hours
   Proton Energies 185.6 Mev

8. University of Uppsala, Uppsala, Sweden
   Dates: June 9-July 8, 1966
   Accelerator time: 166 hours
   Proton Energies 185.6 Mev.

F. NASA Participation:

Members of the NASA, Manned Space Center, Space Radiation and Fields Branch participated in the research effort at the University of Uppsala, at Oak Ridge National Laboratory, and at McGill University. At each facility additional research of special interest to this Branch were accomplished. These included exposure of nuclear track plate emulsions and calibration of various dosimeters. The accelerator time made available to NASA at no charge ranged from 10 to 24 hours at each facility.

II. Theoretical Progress

A. Linear Stopping Power Calculations:

A program for calculating linear stopping power, $dE/\rho dx$; based on the Bethe-Block equation

$$-\frac{dE}{\rho dx} = \frac{0.1536Z}{\beta^2 A}\left[\ell n\frac{2\,mc^2\beta^2}{1-\beta^2} - \beta^2 - \ell n\, I - \frac{\Sigma Ci}{Z}\right]$$

including shell corrections has been completed, tested and used on the SMU, CDC-3400 computer to calculate the correct thicknesses for the pure elements. The mean ionization potential, I, has been evaluated experimentally for each element.

B. Monte Carlo Stopping Power Calculations:

The linear stopping power program has been incorporated into a Monte Carlo transport program which permits Coulomb interaction with both the orbital electrons and the nuclei. This program has been used to verify the stopping power measurement and the energy straggle measured experimentally.

C. Determination of Z/A and I for complex absorbers;

The above programs are being used to determine effective Z, A, and I values for water, bone, meat and fat based on the experimental stopping power measurements. The end result will be a program by which dose, i.e., the total energy absorbed per unit mass of the absorbing material, can be calculated as a function of flux density, type and energy of the ionizing radiation.

D. Calculation of Effective Z/A, and I.:

The effective values of Z/A, and I for each of four plastics studied are being used to obtain a mathematical model for calculating these quantities where the chemical composition and relative abundance of a heterogeneous material is known.

E. Dose Calculation

The computer program is being written to permit calculation of a depth dose distribution in a multilayer, i.e., skin, muscle, bone fat, etc., absorber in a heterogeneous radiation environment. Other options permit (a) the particles to enter everywhere over the surface of the "absorber"; (b) determination of energy lost in transit through the absorber; (c) energy and angular distribution of secondary radiations (nuclear of orbital electrons) to permit study of reabsorption or escape from site of dose interest and (d) the absorber to have a complex geometry.

F. Correlation Between Biological Response and Dose Measurement:

The final step is the determination of a biological response of the chosen subject to the actual (if on a mission) or the predicted radiation environment. Indicative predictions are possible on the basis of human cancer cases and animal irradiations. The biological response itself is a medical study and the responses used in this analysis will be from well qualified sources. The precise determination of the radiation environment which produced the response is a physical study. Translating the laboratory radiation environment into terms of a space radiation environment and correlating the biological response to the space radiation exposure is one of the goals of this research effort.

The main goal of this project is to provide the basic physical data concerning silicon detectors and the true mathematical path to permit the physical measurement or sequence of measurements made with a silicon detector so that the silicon dose and LET measurements can be translated directly into tissue dose and depth dose distribution. It is from these translations that indicative predictions of the biological response can be made.

The data currently being used is that provided by Dr. Borje Larsson from his studies based on his treatment of human cancers using irradiation by 187 Mev protons for treatment and the whole body irradiations of primates by the Bionucleonics Division of the USAF School of Aerospace Medicine. Other studies will be included when it is possible to obtain enough information concerning the laboratory radiation environment to permit a direct translation of the dosimetry into NASA-SMU dosimetry.